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Development of a process resource balancing method based on integration of network planning and multi-agent approach

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Abstract. The article discusses the method of balancing multi-agent resource conversion processes based on the analysis and elimination of bottlenecks, compression procedures and expansion procedures, network planning. A multi-agent process of resource conversion model is used to model and optimize technological, logistic and organizational (business) processes. The method of balancing the multi-agent process of resource conversion is programmatically implemented in an automated system for the release of metallurgical products.

1. Introduction

A multi-agent model of the resource conversion process (RCP) is used [1-4] for formalization and subsequent simulation of [5] technological [6-8], logistic and organizational (business) processes in the automated system for the output of metallurgical products (AS MPP) [9]. The main elements of the RCP model include the following [9]: operations, agents, sources and receivers of resources, resources, funds, applications. The following information describes the principles of construction and modification of the RCP model, based on compression / expansion procedures.

The compression procedure is a procedure for reducing the dimensionality of the dynamic process model. Under the compression procedure, we mean the procedure of structural and / or parametric synthesis (change) of the model of resource conversion processes, which leads to a decrease in the structure and / or in model parameters [9]. The development of model compression algorithms is an urgent scientific and practical task, the solution of which leads to a reduction in experiment time and a decrease in computing resources.

In order to solve the problem of eliminating bottlenecks – to find the most efficient process model, the model extension procedure should also be applied along with the compression procedure. Model expansion procedure (inverse compression procedure) is a procedure for increasing the dimension of a dynamic process model, which allows to increase the throughput of the process model.

2. Principles of building a model of multi-agent resource conversion process

During the constructing of the enterprise process simulation model (in the module for creating process models (CPM)), the following submodels are built:

- the generation of objects (units of production (UP) / projects / orders), such an object in the RCP model will be presented as an instance of an application (transaction) with a set of attributes;



- processes of passing objects (technological, logistic and organizational (business) processes associated with the processing of units of products on machines and equipment, transportation of UPs and the execution of orders / stages of the project / production operations, in the RCP model, the application processing route is formed by a chain of blocks consisting of converters (operations and agents);

- supplies of consumed resources (raw materials, materials and semi-finished products), in the RCP model, the supply route of resources is formed by a chain of blocks consisting of operations and agents;

- work tools (machines, equipment, units, transport, staff).

These subject areas for modeling a set of objects (orders for the production of UP, a portfolio of projects, a portfolio of production orders) dictate the following specific requirements and the corresponding rules for constructing a simulation model:

a) a restriction on the volume of consumed resources in the production process (for example, energy). If the limit on total costs is exceeded, this object (unit of production or order) will become unprofitable;

b) a restriction on the amount of funds used (limited qualified personnel, production capacities of machine tools, units, equipment, transport units, and handling equipment);

c) the strategy of processing objects "first come first out" should be used. Delays in processing (production / execution) of an individual object (UP / order) lead to a number of additional costs (time, energy, material), and can also lead to spoilage and premature wear of equipment and assemblies (breakdowns). In this regard, model blocks must apply a push strategy for the application "object unit of production" (order) (the priority of model blocks increases from the initial stages of processing (execution) to the final);

d) metallurgical production is characterized by the parallel execution of the stages of various work on the output of units of products included in the order. Works (operations / corresponding blocks of the simulation model), related to the critical path, should have a higher priority than parallel works.

These requirements of the subject area and the rules for constructing a simulation model are also in good agreement with Davis's conclusions [10]: "... the ordering rule, according to which the first one is performed with the least reserve, on average gives the best result." The application of the developed principles for constructing simulation models and the method of analysis and elimination of bottlenecks of the multi-agent process of resource conversion [9] allows us to solve the problems of balancing resources.

The multi-agent approach is used to build models of decision-making processes, models of decision-makers. Agents can be of 4 types;

- 1) reactive (based on the model of the machine);
- 2) reactive-intelligent (based on the production knowledge base);
- 3) intelligent (based on the frame expert system);
- 4) hybrid.

Based on the basic principles of business process reengineering (BPR), the meaning of compression procedures can consist of horizontal and vertical compression of investigated process, deployment procedures can increase the throughput of the system (reduce the processing time of production units / documents, fulfill orders, reduce queues, etc.).

The conceptual model of the domain (CMD) of analysis and elimination of bottlenecks of multi-agent process models contains the following elements:

$$CMD = \{MPPR, Exp, ExpOut, Analysis, AnalysisOut, Synthesis, SynthesisOut\}, \quad (1)$$

RCP - many elements of the RCP model; *Exp* - a lot of experiments with the RCP model; *Analysis* - many rules for the analysis of models; *AnalysisOut* - many elements of the analysis results; *Synthesis* - many rules for the synthesis of models; *SynthesisOut* - many elements of the synthesis result.

From the point of view of applying the operational analysis of probability networks to the RCP model when analyzing and eliminating bottlenecks, it is necessary to analyze the following parameters:

1. The utilization rate of the node (nodes correspond to operations and agents, it is also necessary to analyze the utilization rate of the funds).
2. The average duration of an application in the queue for the operation, for the agent (the size of the queue of applications for the operation QOp_{cp} , the average queue of applications for the agent rule $QAgR_{cp}$).
3. The site attendance coefficient and the average processing time of a request in a site.

Figure 1 shows a block diagram of a method for analyzing and eliminating bottlenecks in the RCP process supported by the following modules of the AS MPP:

1. Integration of models (IM).
2. Query Designer (QD).
3. Optimization of enterprise processes (OEP).
4. Creation of process models (CPM).

The results of the method by a typical permanent business process of a metallurgical enterprise are used to change production processes.

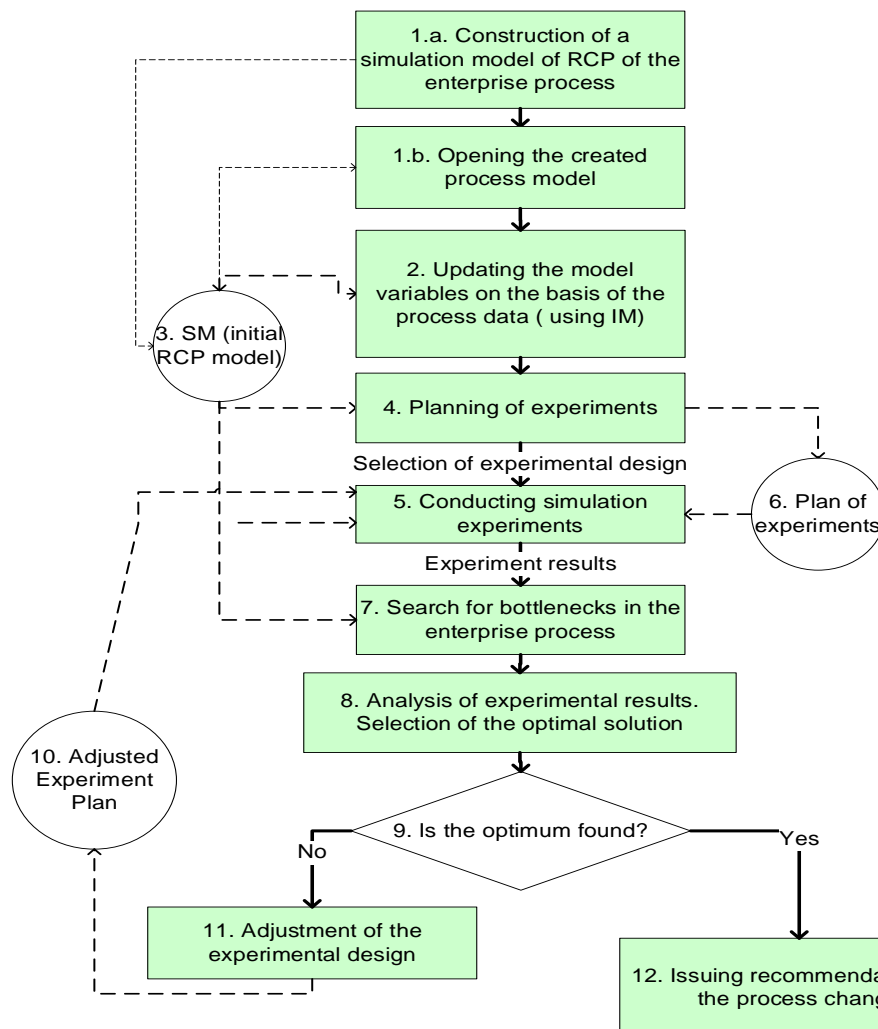


Figure 1. General method schema of bottleneck analysis of multi agent resources conversion process model.

As a result of the experiment, statistics are formed on the implementation of operations, the functioning of agents, the expenditure and formation of resources and applications, and the use of funds in operations of the RCP process. According to the results of the analysis of the statistics of experiments, bottlenecks are diagnosed and a decision is made on the change (convolution / unfolding) of the RCP process. A criterion for stopping the method can also be a decrease in the waiting time to acceptable values for all blocks of the model.

3. Comparison of principles of building models and the method of analysis and elimination of bottlenecks of the multi-agent process of resource conversion with the critical path method

For the analysis of bottlenecks in project management and construction, the network model is the most often used, which, together with the critical path method (CPM) [10]), allows to determine the reserves of the time required to complete individual works. The use of a simulation model, with a push strategy of operation priorities, leads to the effect of the fastest “pushing” of work.

When building a multi-agent simulation model of projects and / or project portfolios, it is necessary to classify operations into 3 types with the corresponding usage of priority types:

- critical path operations (highest priority group) - affects the overall calendar duration of the project;
- operations and chains of operations preceding critical path operations (medium priority group);
- other operations not preceding critical path operations (lower priority group).

Formulation of the problem:

Consider the case of simultaneous execution of two projects for the case when 2 different works can be performed in parallel in time (2 resources are available) and the highest priority is assigned to works related to the critical path (and these priorities are the same for different projects (objects)).

The following situations are possible related to the start time of projects (Figure 2):

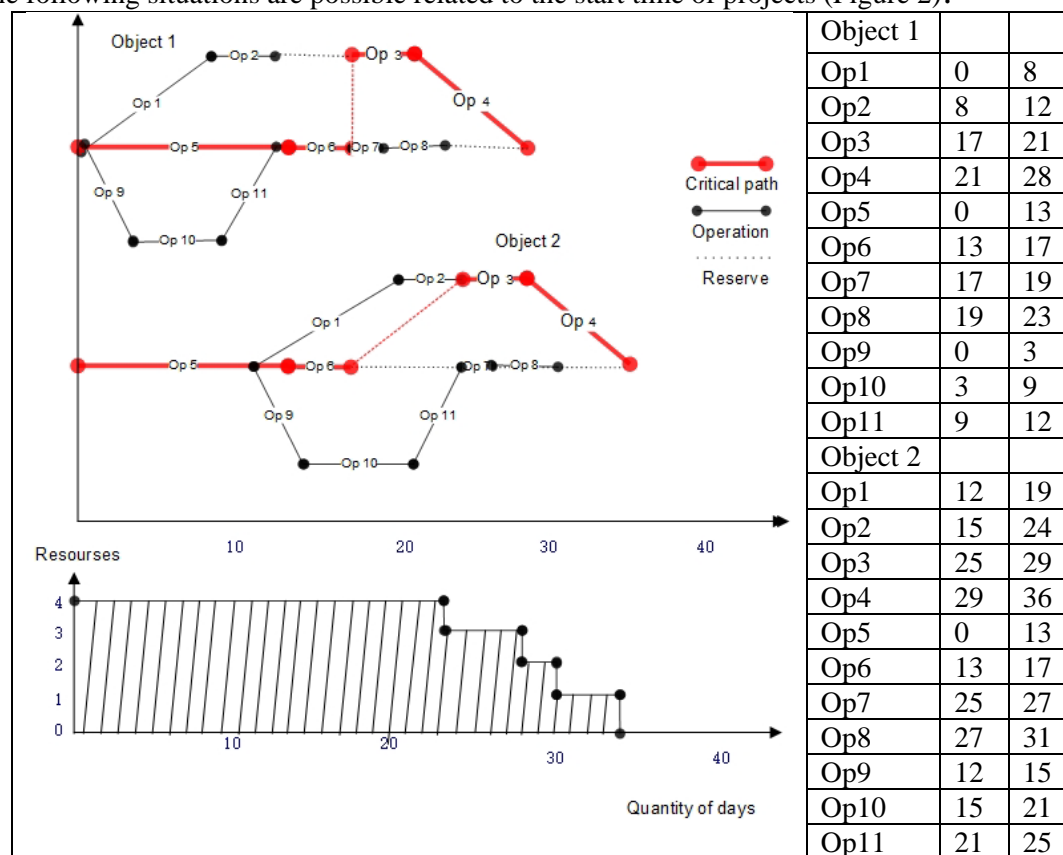


Figure 2.A. Initial view of projects.

Network diagram of projects for 4 resources, without a bias in the launch of Object 2 and the launch of O2.Op1 (on day 11); O2.Op9 (on day 11); O2.Op3 (on day 24); launch O2.Op7 (on day 24).

Work is forbidden to interrupt (Total duration 36 days).

Object 2 incurred a fine of 8 days for Op3 critical path operations.

By that time, when the whole complex of works should be completed, the workshop has just started the main stage of work.

What caused this penalty? At the stage from day 17 to day 25, all resources were occupied with preparatory and basic work. At each object, 2 parallel operations were carried out.

This network diagram allows to visually see how you can allocate resources in order to complete the full range of work at Objects 1,2 on time. Moreover, in addition to the allocation of resources, this graph clearly shows that the process has drawbacks. Total, thanks to the network diagram of Figure A, we clearly saw that potentially, by optimizing the process, it is potentially possible to save 5 days.

It is also possible to organize a combination of certain operations as an optimization of resources (work of teams).

Network diagram of projects for 4 resources (Figure 3), with the launch of O1.Op10 (on day 12), O1.Op7 (on day 21), O1.Op8 (on day 24). Without a delay in starting Object 2 and starting O2.Op1 (on day 3), O2.Op9 (on day 15), starting O2.Op7 (on day 23) and interrupting Op7 for 2 days (total duration 32 days), O2.Op8 (on 28 day). Object 2 incurred a fine of 4 days for of Op8 non-critical path operations.

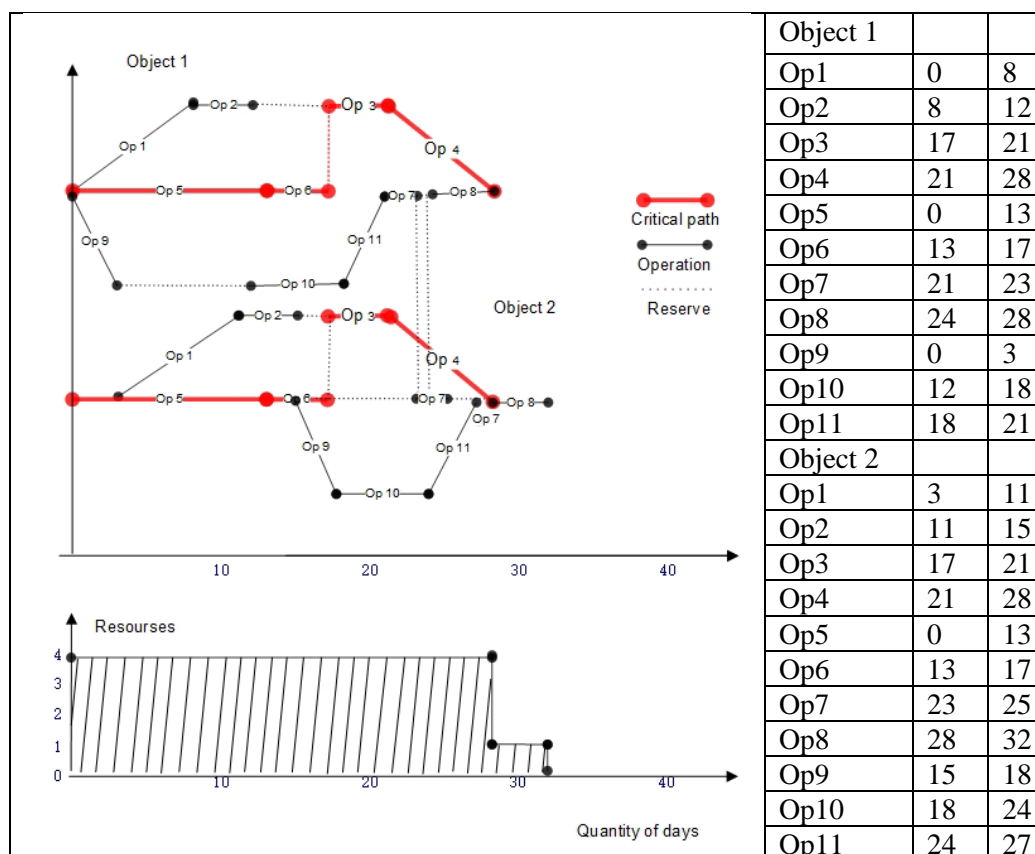


Figure 3. B. Improved view of projects.

Conclusion: Complex distribution of works in Figure 3 B, but, compared with A, there are no penalties for delaying the work of the critical path.

From the calculation results, it is clear that the uniformity of the use of resources can be exerted by both the structure of the network diagram and approaches to balancing resources (including the

selection and fixing of a certain operation to a resource). The shape of the “tail” of the consumption function of the network graph resource (and, accordingly, the utilization coefficient) is affected by the proportionality of the number of parallel operations to the amount of resources. When balancing the distribution of resources between the tails of network schedules of different objects (orders for the production of UPs), the effect of an increase in the terms of individual objects can be observed and, thereby, the penalty time of an individual object can increase.

It is also worth noting the existence for the subject area of the processes of a metallurgical enterprise of specific objects (consumed resources and applications) with a very short useful life, which include a unit of product that left after processing at the unit and which must be processed at the next unit. Meanwhile, temperature and its corresponding physical parameters must be maintained in a given range according to technology.

The results of the comparison of the methods are presented in Table 1. The word “YES” in the table means that the method supports the corresponding functionality indicated in the column “Comparison criterion”. These principles of building models have also been tested on the task of analysis and modeling of building processes [9].

Table 1. Comparison of the new method and the critical path method

Comparison criterion	CPM	RCP
Usage of funds Accounting of	YES	YES
Resource accounting	NO	YES
Resource Supply Accounting	NO	YES
Accounting for the lifetime of a consumed resource	NO	YES
Balancing funds	YES	YES

4. Conclusion

In this paper, the following additional principles (in terms of setting priorities for operations processing applications) for constructing simulation models for subject areas of technological, logistic and organizational (business) processes are determined by examples of network diagram calculations:

1) when constructing a simulation model of a process or portfolio of orders for the output of units of products, it is necessary to classify all operations according to three types of priorities: the highest - for critical path operations; medium - for operations preceding critical path operations; lower - for other operations;

2) if the subject area and technological operations allow the use of interruptions of operations, then when constructing a model, relative and absolute priority can be used for operations, otherwise, the prohibition of interruptions is established;

3) the use of “push” strategy (FIFO) when modeling the processes of fulfilling orders for the manufacture of units of products.

The obtained theoretical results (the method of balancing the multi-agent process of resource conversion) and the developed principles for constructing models made it possible to implement software for the process optimization module of the enterprise of an automated metallurgical production system, which uses expert, simulation and multi-agent modeling, network planning as its basis.

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